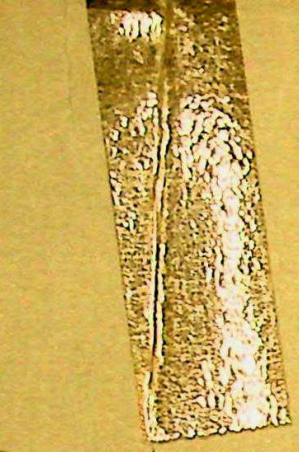
THE OPTICS OF METALLOGRAPHY

By W. [illegible]son



NOTE:—Practically all of the important developments in equipment for metallography, since the first publication of this article, are embodied in the new Bausch & Lomb Large Metallographic Equipment. For this reason, a rather complete description of this apparatus has been incorporated in this revision.

In order that no confusion may exist as to which equipment is referred to, all descriptions and illustrations of this new apparatus are marked with an asterisk, thus(*).

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THE OPTICS OF METALLOGRAPHY

By W. L. PATTERSON

350/91

OBJECTIVES

The objectives undoubtedly constitute the most important part of the microscope. Their quality determines the final results.

The objective is so called because it is nearest to the object. Figures 1, 2, and 3 show respectively the 16, 4, and 1.9 millimeter objectives of the usual type, but they are made in a variety of focal lengths, numerical apertures, and styles of mount by various makers. Following are given the usual focal lengths and numerical apertures (N. A.) of achromatic objectives:

Focal Lengths Millimeters	*Numerical Aperture (N.A.)*	*Type of Lens*
32	0.10	Single achromatic lens.
16	0.25	Two achromatic doublets.
8	0.50	These three have non-achromatic front with 2 achromatic doublets. 6 lenses in all.
4	0.85	
3	0.85	
1.9	1.25	Fluorite construction, semi-apochromatic.
1.9	1.32	

Further reference will be made to the apochromatic objectives later. The focal length of an objective does not indicate its working distance, but means that the combination of lenses composing the objective is equal in focus to a single lens of the stated focus. Thus the working distance for the—

16	millimeter	focus	= 7	millimeters
4	"	"	= 0.30	"
1.9	"	"	= 0.15	"

An objective may be said to possess seven qualities: magnifying power; aperture, or numerical aperture; resolving power; depth of focus, or penetrating power; illuminating power; flatness of field; and defining power. To fulfill all of these requirements in a satisfactory manner necessitates considerable skill upon the part of the optician. These qualities will be discussed one by one.

Magnifying power usually is stated in the catalogues of various makers in terms of the combination of a certain objective, certain eyepiece, and tube length at a predetermined image distance. While tables given in the catalogues are approximately correct, the magnification stated will be obtained only if the conditions given are fulfilled. If the tube length, that is the distance between objective and eyepiece, is increased or decreased, or an increase or decrease in image distance is taken as in photography, the magnification tables will not prove correct. Tables given in catalogues are often for visual work and are based on an apparent or virtual image being formed in space at a distance of 250 millimeters from the eye. This

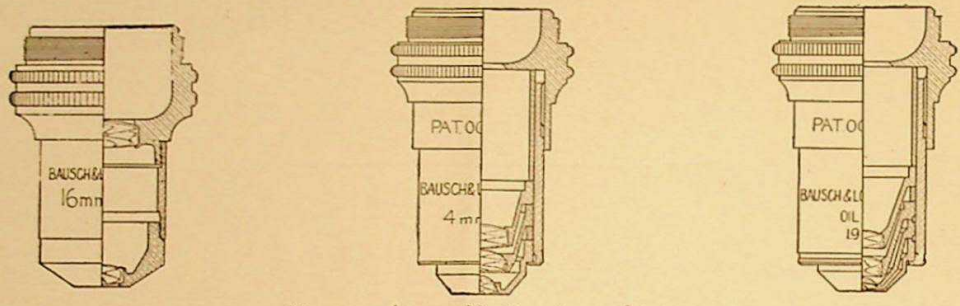


Fig. 1—16 mm objective of usual type
Fig. 2—4 mm objective of usual type.
Fig. 3—1.9 mm objective of usual type.

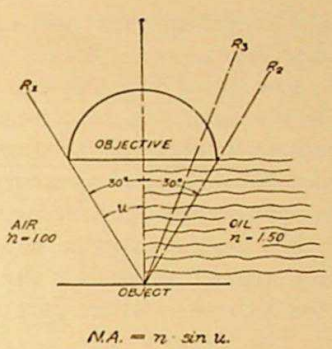
apparent size will vary with persons having near—or far-sighted eyes, but the normal distance is taken as 250 millimeters and the size of the image is the same if projected on the ground glass of a camera at 250 millimeters.

Makers of objectives also give in their catalogues the initial magnification of their several objectives, that is the magnification they give at a certain distance unaided by the eyepiece. These tables of initial magnification will be found to vary in different catalogues even though objectives are of the same focal length, this being due to the different systems of calculating magnifications. It will be found, however, that for the same focus of objective, the same focus of eyepiece, and the same tube length, the figures nearly agree. Some makers use a number system for both eye pieces and objectives, but in making comparisons only focal lengths should be considered.

In the large inverted forms of metallurgical microscopes the distance between objective and eyepiece is usually about 40 millimeters longer than in the ordinary table microscope, and therefore, the magnification is increased some 25 percent even with the same focus of objective and eyepiece; hence the difference in magnification tables for this microscope. With the many variable factors in different outfits it is difficult to make comparisons, and it is best to calculate the magnification for the particular outfit being used, especially as regards camera magnifications. To obtain the exact magnification at the ground glass of the camera, and therefore of the photograph, it is best to project a stage micrometer upon the ground glass and measure its magnified image. Micrometers graduated upon metal may be obtained for this purpose. The rulings are in tenths and hundredths of a millimeter. They are placed upon the stage and illuminated the same as a metal specimen. After focusing upon the ground glass the magnification can be measured directly without further calculation.

The aperture, or numerical aperture (N.A.) is a property to which many buyers of microscopes probably pay little attention, but it is nevertheless an important quality of an objective. The diagram in Figure 4 is shown in an attempt to simplify the theory of numerical aperture. If we

assume that few, if any, objects are perfectly smooth, then light is dispersed from every point on the surface of an object in all directions up to 180 degrees. Only an extremely narrow pencil of this can be received by the unaided eye. The apparent problem of practical optics is to be able by means of lenses to gather and bring to a focus as many of the unadmitted rays as possible. In early investigation it was found that the objective which gathered in the greatest angle of rays gave the greatest resolving power.



N.A. = n sin u.

Fig. 4—Diagram showing theory of Numerical Aperture.

If only dry objectives were to be considered, we might make a comparison on the basis of angular aperture, that is the angle of the cone of light which is admitted to the front lens of the objective and reaches the eye. This is important, as internal diaphragms reduce apertures, but these apertures may be measured readily by special instruments.

A thorough study by Professor Abbe, however, proved that the only exact method for comparison of objective apertures was by comparison of the sines of the extreme admitted radiant pencils, and, when the media differed between the object and the objective, of the refractive indices of those media, which are 1.00 for air, 1.33 for water, and 1.50 for cedar oil. It is very evident that rays emanating from an object and passing to the objective will travel in different angles according to the media through which they pass, owing to the different refractive indices or bending powers of such media.

In Figure 4 is shown a ray R_1 leaving the object at an angle of 30 degrees, passing through air and just entering the extreme edge of the front lens of the objective. A second ray R_2 leaving the object at the same angle and passing through oil will be bent so as to fall within the edge of the objective lens, as shown by R_3. It is obvious that a ray leaving the object at a still greater angle than R_2 and passing through oil will be bent so as to pass into the objective. Thus a wider angle of rays is collected in case of the oil-immersion objective than in the dry objective.

It will be seen that angular aperture can not be a comparative measure for the two kinds of media. Abbe found that a value could be expressed for the different conditions by taking the sine of one-half the angle of aperture and multiplying it by the refractive index of the media between object and objective; hence the formula:

Numerical aperture (N. A.) = n sin u

where n = refractive index of media: air 1.00, water 1.33, oil 1.50, and u = one-half the angular aperture.

Thus the numerical aperture on the air side would be

$$1.00 \times \text{sine } 30^\circ = 1.00 \times .5 = 0.50$$

and on the oil side

$$1.50 \times \text{sine } 30^\circ = 1.50 \times .5 = 0.75$$

This gives a method of comparison between dry- and oil-immersion objectives.

The resolving power, which is the property by which an objective shows distinctly separated two small elements in the structure of an object, is directly proportional to the numerical aperture; thus an objective of 0.50 numerical aperture, as in the 8 millimeter, has twice the resolving power of the 16 millimeter, or 0.25 numerical aperture.

If a very narrow central pencil is used for illumination, the finest detail that can be shown by the microscope, with high enough magnification, is equal to $\frac{\lambda}{\text{N.A.}}$ where lambda is the wave length of the light used for illumination, say one-half micron. The wider the pencil used for illumination, the greater the resolving power until a maximum is reached, when the width of the pencil is sufficient to fill the whole aperture of the objective. In this case the resolving power is twice as great, the finest detail that the objective can show being now equal to $\frac{\lambda}{2 \times \text{N.A.}}$. For a 0.50 objective the first would be one micron with reduced aperture, and the second one-half micron with full aperture.

For practical purposes we may take the rule that the numerical aperture multiplied by 100,000 will give the number of lines per inch which can be resolved theoretically by a given objective. Thus, pearlite of say 25,000 laminations per inch should be easily resolved with an 8 millimeter objective of 0.50 numerical aperture, and a suitable eyepiece and bellows draw can be used to magnify the image to the size desired, say 400 diameters. On the other hand, an objective of say 0.25 numerical aperture could scarcely be expected to resolve this structure no matter how high we magnify the image by eyepieces or bellows extension. The magnification should never exceed 1000 times the numerical aperture; preferably it should be somewhat less, dependent upon the quality of the objective.

Depth of focus (known also as depth of sharpness or penetration) is another important factor which is often not clearly understood. It depends on the numerical aperture and the magnification, and is inversely proportional to both. The formula used to express depth of focus is $\frac{1}{\text{N.A.}}$; therefore, the higher the numerical aperture and the higher the magnification the less the depth of focus. It is beyond the power of the optician to change these conditions. Every effort aiming at an increase of the depth of focus, for instance, by inserting diaphragms above the back lens of the objective, must necessarily decrease the effective diameter of the back lens and thus decrease the numerical aperture, thereby lowering the efficiency of the objective as regards resolving power. It may be advisable at times to introduce such diaphragming for the work to be done, and it will be shown later how such a change can be made by proper use of the illuminating system. However, objectives that show greater depth of focus than others of the same numerical aperture are not well corrected for other qualities.

The illuminating power of an objective is equal to the square of the numerical aperture, and objectives can be so compared; that is, a lens of 0.25 numerical aperture has an illuminating power of 0.062, while one of 0.50 numerical aperture has 0.25 or 4 times as great, provided it is used at the same magnification. "Flatness of field as such," said the late Dr. Carpenter, "is an optical impossibility." But by using compensation or hyperplane eyepieces to correct the margin of field, better effects are obtained, and by increasing the depth of focus by reducing the used aperture, apparent flatness is secured but at the expense of resolving power, as stated before. As an illustration of this we refer again to the statement concerning the depth of focus, which is equal to $\frac{1}{\text{N.A.}}$, hence, for an objective of 0.50 numerical aperture, the depth would be 2, while for an objective of 0.85 numerical aperture, the depth would be 1.17.

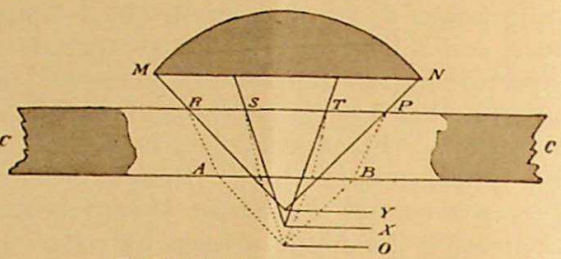
As depth of focus also varies with the magnification, if we use the above lenses at the same magnification we should naturally have greater depth in the objective of 0.50 numerical aperture, and if this gives sufficient resolving power for the work in hand it may be used to obtain a flatter field.

Defining power depends upon the finest correction of spherical abberation and chromatic aberration, the perfect centering of the lenses of the objective, and in fact on the general excellence of the mechanical work involved in the making, and it is here that the optician must show his skill. It should be borne in mind that the finer the definition of an objective, the more sensitive it is to incorrect focusing and to slight changes of the adjustment through vibration, etc. In constructing objectives their formulae should be based upon rigorous computations, all elements of construction, such as glass, radii, thickness of lenses, separation, etc., being determined in advance wholly without recourse to experiment. This method of construction is the only one insuring uniformity in optical systems of such intricacy as a microscope objective.

It will be well to consider at this time the effect of tube length, that is, the distance between the objective and the eyepiece with which it is used. Most of the objectives used on biological and smaller metallurgical microscopes are corrected for a mechanical tube length of 160 to 170 millimeters. By mechanical tube length is meant the distance from the shoulder against which the objective screws to the shoulder against which the eyepiece rests. In the case of the larger metallurgical stands of the inverted type this distance is usually longer, owing to reflections necessary to secure an inverted stage and a convenient position for the viewing tube. Therefore, the objectives used on this type of microscope should be corrected for this extra length. The use of objectives at incorrect tube length, especially in powers over 100 diameters, will result in inferior definition. This is especially true in metallographic work.

Objectives for metallurgical work must also be corrected for use without coverglass, as specimens of metal are examined without covering.

All objectives used in biological microscopes are corrected for the refraction which takes place when the ray from the object passes through a



The effect produced by a cover-glass on the corrections of an object-glass.

Fig. 5—Effect of coverglass upon focus.

thin piece of glass. These objectives are not suited for use on uncovered objects, and if used in metallurgical work only inferior results will be obtained except with the very lowest powers, such as 16 millimeters or lower. To show the effect of cover-glass, Figure 5 has been taken from Carpenter's book on the microscope. It will be seen that without the cover-glass an ordinary microscope objective would focus at different planes for the central and marginal zones, as shown at points Y and X, but with the refraction of the cover-glass the rays all focus at the point O.

Aplanatic system. Under-corrected system.

Fig. 6—Undercorrected system obtained without use of coverglass.

Therefore if the ordinary objective is used without cover-glass, it will work as an under-corrected system, as shown in Figure 6, whereas when corrected for use without cover the objective should be perfectly aplanatic, as shown at the left, all rays focusing at one point. This correction cannot always be accomplished by changing distances between lenses but requires special computation. The oil-immersion objective, however, needs no special correction as regards cover-glasses, because the immersion oil and cover-glass are of the same refractive index, and if the cover is missing, the additional strata is made up by a thicker layer of oil. The tube length, however, must be correct even in this case.

As to the objective mounts, both long and short mounts are used in metallurgical work. The short mounts should always be used with mirror or prism illuminators so as to bring the illuminator as near to the back focus of the objective as possible. The tendency of late, however, has been to use short mounts for all kinds of illuminators.

The objectives previously described are of the achromatic type, but the same characteristics are also found in the apochromatic objectives, and they are even more sensitive to deviations from the standards for which they are made. The usual focal lengths and numerical apertures are as follows:

Focal Length	*Numerical Aperture (N.A.)*	
	apochromatic	*achromatic*
16 millimeters	0.30	0.25
8 "	0.65	0.50
4 "	0.95	0.85
3 "	0.95	0.85
2 "	1.30	1.25

It will be seen that the numerical apertures are somewhat greater in the apochromatic objective. This means increased resolving power and other features attending higher aperture. These lenses have other improvements than increased aperture.

The word apochromatic means free of color and is illustrated by Figure 7. If we were to form an image with an ordinary lens of non-achromatic form, a ray of white light coming from the object would be broken up into the several colors of the spectrum and images would be formed at different distances from the lens, corresponding to each color. There would thus be a series of images, one behind the other, ranging from violet to red, the shorter waves being refracted more than the longer ones.

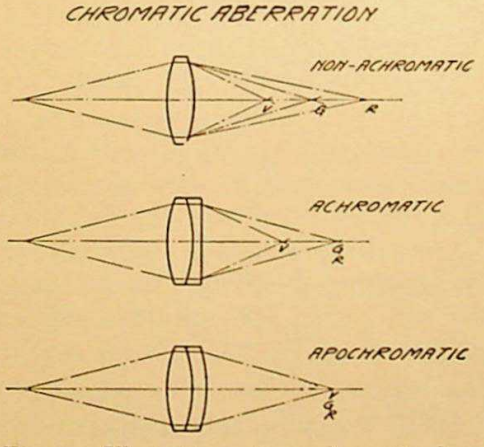


Fig. 7—Illustration of apochromatic lens.

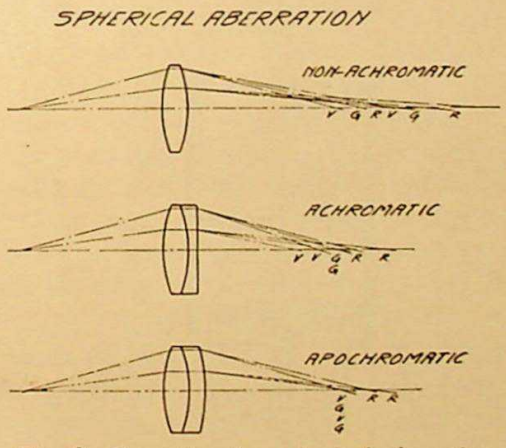


Fig. 8—Correction for spherical aberration.

In the standard achromatic objective, two of these colored images would be combined, and in apochromatic objectives three colored images would form in the same plane, and as the violet rays are brought to a focus at the same plane as the applegreen visual rays, these objectives are excellent for photographic purposes, even when used without filters. As shown by Figure 8, the correction for spherical aberration is more perfect. Spherical aberration refers to the fact that in an ordinary uncorrected lens the portion of a ray coming through the center and the portion coming through the outer zones are focused at different planes. In the uncorrected lens this applies to all colors; in the achromatic objective the correction is made for one selected color, say green, and in the apochromatic for two colors. Therefore, for the very finest class of investigations the apochromatic objectives are essential owing to their finer color and spherical corrections. These corrections are accomplished by the use of special glasses

and a transparent mineral substance known as fluorite. Another series of objectives now offered upon the market is the 4 millimeter dry and 1.9 millimeter oil immersions, known as semi-apochromatic objectives. They have one fluorite element and are much better than the regular achromatic objectives. They make a good compromise where cost will not permit the purchase of apochromatics.

EYEPIECES

The second part of the optical equipment to be considered is the eyepiece, so called because it is used near the eye. This may, however, lead to some confusion, as the eyepiece is also necessary when forming the image upon the ground glass of the camera. Some users of this class of apparatus have been found who thought the eyepiece was needed only in visual work. Small photographic lenses are used without eyepieces, as later explained. The ordinary eyepiece shown in Figure 9 is known as the

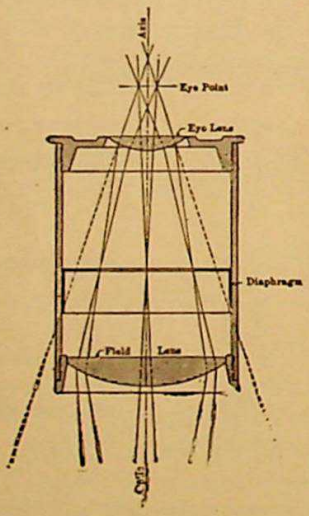
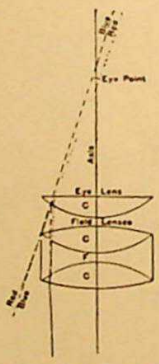


Fig. 9—Eyepiece of Huygenian form.



POSITIVE COMPENSATION OCULAR
(From Spitta, p 110).

Fig. 10—Compensation type eyepiece.

Huygenian form after its designer. It consists of the two non-achromatic plano-convex lenses with a diaphragm for limiting the field between them. The upper lens is known as the eye lens and the lower as the field lens. Huygenian eyepieces are made in a variety of powers, as 5×, 6.4×, 7.5×, and 10× and 12.5×, these designations meaning that they magnify the image formed by the objective by these amounts. Different makers used different designations for their eyepieces and this is likely to cause confusion if attempt is made at comparison.

In the case of Leitz and Zeiss the eyepieces are numbered from 0 to 5, but the eyepieces of the Bausch & Lomb Optical Co. are marked with their magnifying power as 5×, 10×, etc.

A new eyepiece known as the hyperplane produces a flatter image plane than the Huygenian eyepiece and allows for a larger field of view, well

adapted for photomicrography. These eyepieces have a compensation about half-way between the Huygenian and compensation eyepieces described below.

The hyperplane eyepieces are made in powers from 5 × to 20 × and may be used with all classes of objectives.

Another form of eyepiece is known as the compensation eyepiece, shown in Figure 10, so called because it compensates for the variation in size of the blue and red images given by the apochromatic objective. While the apochromatic objective is so constructed as to bring these colors into focus at the same plane as previously stated, the images formed are not of the same size, and this variation is neutralized by the compensation eyepiece. The latter should, therefore, always be used when one is using apochromatic objectives, and may also be used to good advantage with the high-power achromatic objectives. The compensation eyepieces of various makers are not always interchangeable with different apochromatic objectives.

These eyepieces vary in construction and in the number of lenses according to their power. They are made in powers from 5 × to 25 ×, much higher than the Huygenian type, and it is possible to use these high powers with the apochromatic objectives owing to their finer color correction.

There is another type of eyepiece known as the projection eyepiece, in which the eye lens or lens nearer to the photographic plate is adjustable according to the bellows extension of the camera. With this adjustment one is able to use the objective in the same relative position to the object as it is when used for visual work. Some of these eyepieces have a very small opening in the diaphragm, which is likely to indicate that the field is unusually flat.

It is possible to get effects similar to those produced by the projection eyepieces, with ordinary eyepieces, by partially withdrawing them from the eyepiece tube when making photographs. This distance may be found by the formula:

$$\frac{\text{square of eyepiece focus}}{\text{length of camera draw}}$$

Thus for a 5 × eyepiece of 50 millimeter focus and a bellows draw of 250 millimeters, the eyepiece would have to be extended 10 millimeters, or it may be determined by experiment. It will be seen that the distance becomes greater with low-power eyepieces and short bellows draw. This adjustment keeps the objective in the same relation to the object as when used in visual work, as previously stated, and preserves its best spherical correction, tending to flatten the fields.

Too much stress cannot be laid upon the necessity of keeping all of the optical parts clean and free from dust, grease, or finger marks. Poor results are often due to this neglect.

VERTICAL ILLUMINATOR

In Carpenter's book on the microscope it is stated that the first vertical illuminator was made and used by Prof. H. L. Smith of Geneva, New York. Smith's illuminator consisted of a piece of speculum metal so placed as to reflect light down through one side of the objective, the image returning through the opposite side. The plane-glass illuminator is said to have been designed by Beck of England. In this form the light is reflected by the surface of the glass, through the objective and the image returns from the specimen through the glass to the eyepiece. Formerly much flare was experienced in using this type of illuminator, but it can be eliminated by proper illuminating appliances and diaphragms. Both forms of illuminator are in use today, the first in the form of mirrors and the latter much in its original form.

The mirror and prism types are preferred by some workers, and while they are satisfactory for low powers and relief work, they reduce the available aperture of the objective by nearly one-half with consequent reduction in resolving power. They do give increased illumination, due to total reflection, and may be used for projecting metal specimens with low powers when several observers wish to study the image. For high powers and utmost resolution, the plane-glass reflector is best.

Vertical illuminators have appeared from time to time in many forms. The one shown in Figure 11 is a base model to which can be fitted mirrors, reflector, plane-glass reflector, lenses and diaphragms, as desired. For visual work, side tubes with lenses and lamps may be attached and used successfully, but when high-power illumination is used and the beam of light must be carefully centered to the objective, the best results can be obtained by having condensers and lamps on separate standards. A recent addition to this type of illuminator consists in clamping screws, whereby all adjustments can be locked so that once adjusted the illuminator cannot be deranged easily. Care must be exercised to keep the glasses of the il-

Fig. 11—Vertical illuminator to which can be attached mirrors, reflector, plane glass reflector, lenses and diaphragms as desired.

Fig. 12—Condenser and iris diaphragm mounted on a separate standard.

luminator clean and to prevent distortion by bending the mount when cleaning as it will tend to destroy the definition.

Figure 12 shows a condenser and iris diaphragm mounted on a separate standard in place of mounting it integral with the vertical illuminator. This is termed by the makers a supplementary condenser, to distinguish it from the condenser at the arc lamp. Its use and adjustment will be explained later.

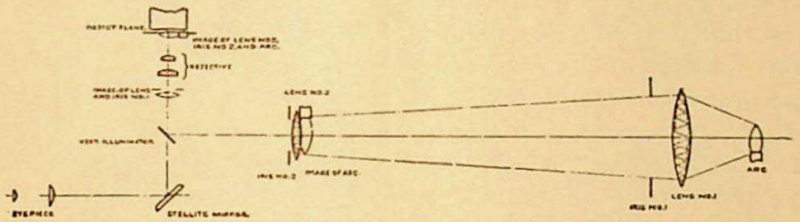


Fig. 13—Method for obtaining critical illumination.

Critical Illumination: It is generally agreed by expert microscopists that the best results are obtained when the specimen is examined or photographed with critical illumination. Critical illumination is obtained when the image of the illuminant and the surface of the specimen are about in one plane, also, when removing the eyepiece and examining the back lens of the objective through a pinhole cap, it is possible entirely to fill the lens with light. In Figure 13 is shown how this kind of illumination may be obtained. The arc or filament is nearly imaged on the supplementary condenser No. 2 by the aspheric condenser No. 1 with a distance of about 25 to 30 inches between the two lenses. This should give an image of the illuminant of about 25 to 30 millimeters diameter. The image should be slightly ahead of the supplementary lens No. 2 if an arc is used so as to avoid imaging gas bubbles upon the specimen.

An image of the fully and evenly illuminated aspherical lens No. 1, and its iris diaphragm, referred to later, are projected into the back focus of the objective by means of the supplementary condenser No. 2 and the vertical illuminator. The supplementary lens is of such focus and set at such distance from the objective, (that is, the same optical distance as the eyepiece diaphragm from objective) that the image of the arc, the evenly illuminated lens No. 2 and its iris, are imaged by the objective upon the specimen when the objective is at proper focus. By closing the iris in front of the aspheric condenser, the aperture of the light cone entering the objective is reduced, similarly to that accomplished on some outfits by placing an iris diaphragm on the side of the vertical illuminator. This reduction of the light cone below the aperture of the objective gives decreased illumination, and decreases the numerical aperture with attending results; for example, less resolving power, greater depth of focus, and greater flatness. Full apertures are obtained with iris opening of 16 millimeters for 4 millimeter objectives, and 18 millimeters for 16 and 32 millimeter objectives.

Closing the iris of the supplementary lens No. 2, when imaged on the specimen, reduces the size of the illuminated spot upon the specimen, and hence the size of the visible field. By just opening this diaphragm enough to clear the field of view, unnecessary rays are cut off, so that they will not cause reflections on the tubes of the objective, illuminator, etc.

The light returning from the specimen after passing through the objective and vertical illuminator, is reflected by a stellite mirror to the eyepiece. The use of a metal mirror reduces all chance of flare which might come from the plane surface of a glass prism.

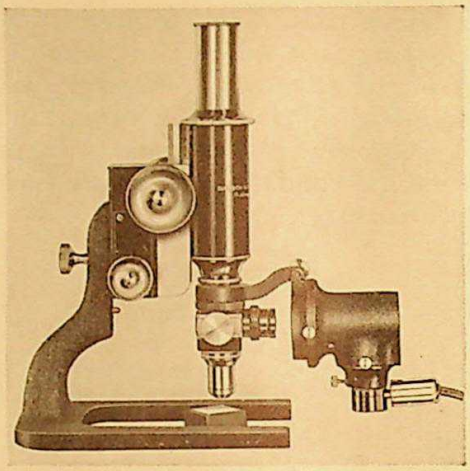


Fig. 14—Tassin microscope with illuminating device attached to vertical illuminator.

With the appliances just mentioned, the illumination scheme for metallurgical work as described in the Zeiss circular, Micro No. 89, may be obtained, although the adjustments are somewhat different. It should be noted that in both visual and photographic work, decrease in illumination should be accomplished by filters and not by diaphragms which reduce aperture, unless reduction of aperture is desired to secure certain results. It will be shown later how these optical parts are adjusted to secure the best results as regards centering.

MICROSCOPES

Any ordinary microscope with proper optical parts may be used in the examination of metals, but it is, in this case, either necessary to mount each and every specimen at a fixed height to avoid readjustment of the illumination or to have an illuminating device attached to the vertical illuminator, as shown in Figure 14. This stand is somewhat like the workshop microscopes of Swift and Watson, after the design of Mr. Stead. The illuminating device consists of a 6-volt incandescent lamp, operating on the regular 110-volt circuit, and two condensers. As can be seen from the illustration, it is attached to the illuminator and moves with it and the optical parts. It may be applied to any ordinary microscope, and the results obtained are good for magnifications up to about 200 diameters in visual work. It may also be used in photography for about 100 magnifications, but of course cannot compare with the better instruments and cameras.

The general form of stand for metallurgical work, however, is one in which the stage and specimen are movable by rack and pinion, as by this method varying thicknesses of specimen can be accommodated without

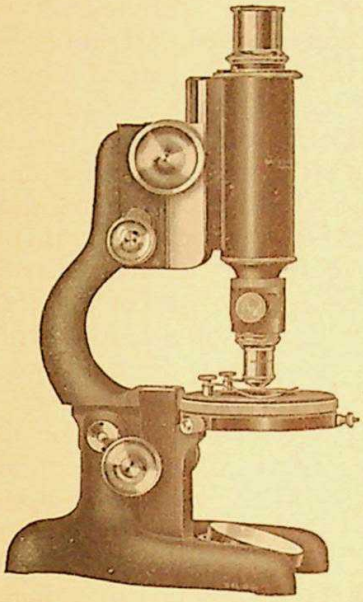


Fig. 15—Typical metallurgical microscope for student use.

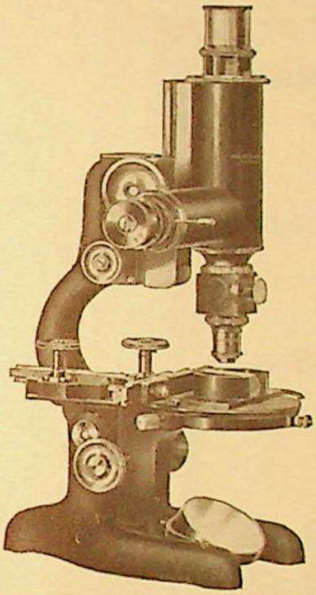


Fig. 16—Same as instrument in Fig. 15 but with mechanical stage and horizontal camera tube attached.

deranging the illuminating system. Instruments of this type require the mounting of the specimen in wax or other form of holder. In the case of steel specimens, a Sauveur magnetic holder may be used, the specimen being held from the under side by magnetism.

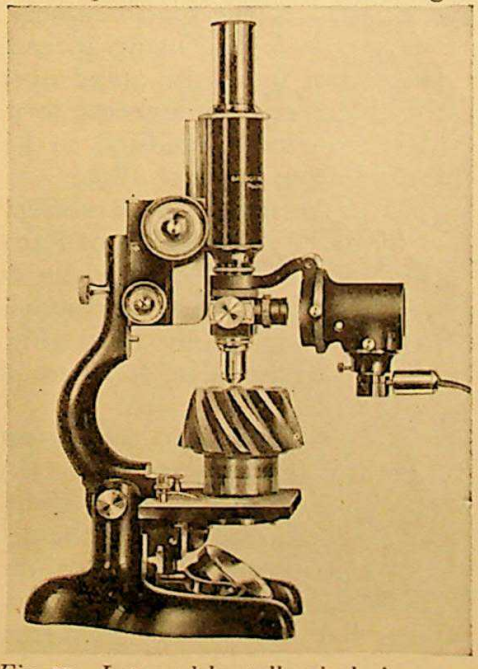


Fig. 17—Late model metallurgical microscope, with unusual range for height of specimen.

Figure 15 shows a typical form of metallurgical microscope to which a mechanical stage may be attached if desired. The stand illustrated in Figure 16 differs from the preceding model in that it has a side tube for connecting to the camera, so that visual observations can be made without disconnecting or moving the camera, the only operation necessary being the withdrawal of the side tube, with its prism, from the optical axis when making visual observation or in adjusting the light and the specimen.

A later development of this type of stand (Figure 17) provides more space between the stage and objective, an improved type of vertical illuminator and a series of adjust-

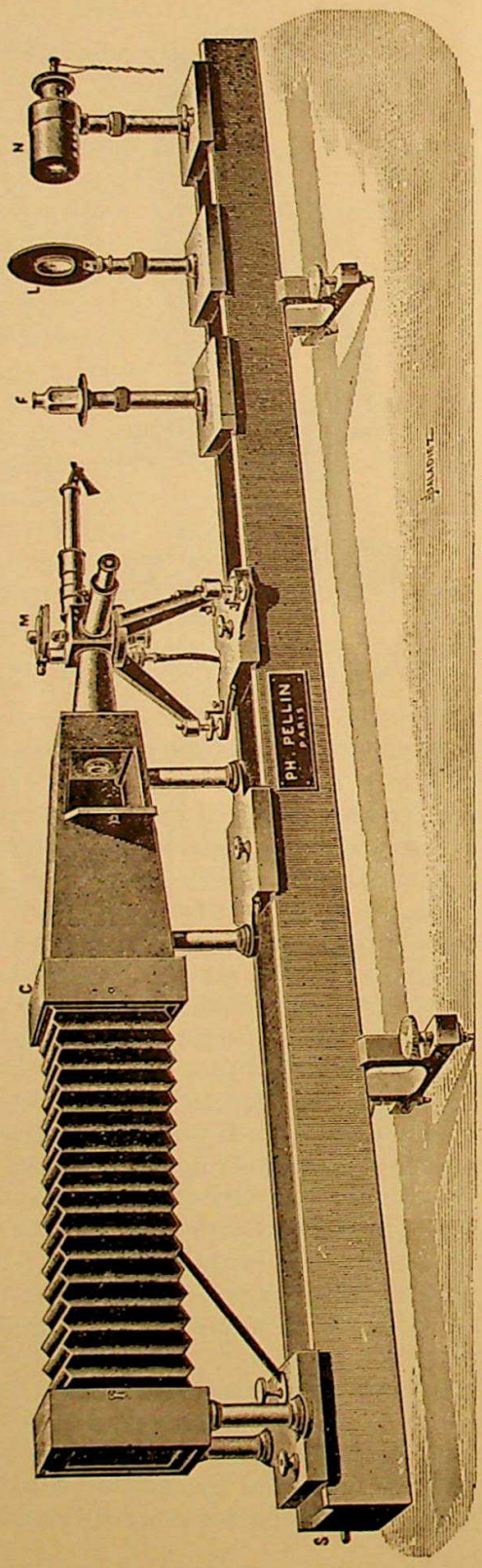


Fig. 18—Le Chatelier inverted metallurgical microscope. Ph. Pellin.

ments and attachments which makes it an almost universal instrument for general laboratory purposes. It may be quickly converted from vertical to oblique or substage illumination, may be fitted with polarizer and analyzer for either opaque or transparent specimens, and is adaptable through the use of suitable attachments for either binocular or monocular wide field work at comparatively low powers. It is particularly adapted for metallographic work in connection with any of the standard photomicrographic cameras as the stage adjustment permits focusing without disarranging the alignment of the illuminating equipment.

Many workers prefer a stand of the inverted type, that is, one in which the stage is above instead of below the objective, and in which it is necessary to prepare one surface of the specimen only, the polished face being placed, face down upon the stage over the objective. The inverted form of microscope is credited to Le Chatelier in the year 1897.

It has been made in a variety of forms, first by Pellin of Paris (Fig. 18), later by Dujardin & Company (Fig. 19). Other models have been made by Leitz (Fig. 20) of Germany and Reichert of Austria.

*Figure 21 shows the latest large inverted microscope of the Bausch & Lomb Optical Company, which embodies all the desirable features of a metallurgical microscope. This instrument has been so designed that relative vibration between the specimen and the objective can

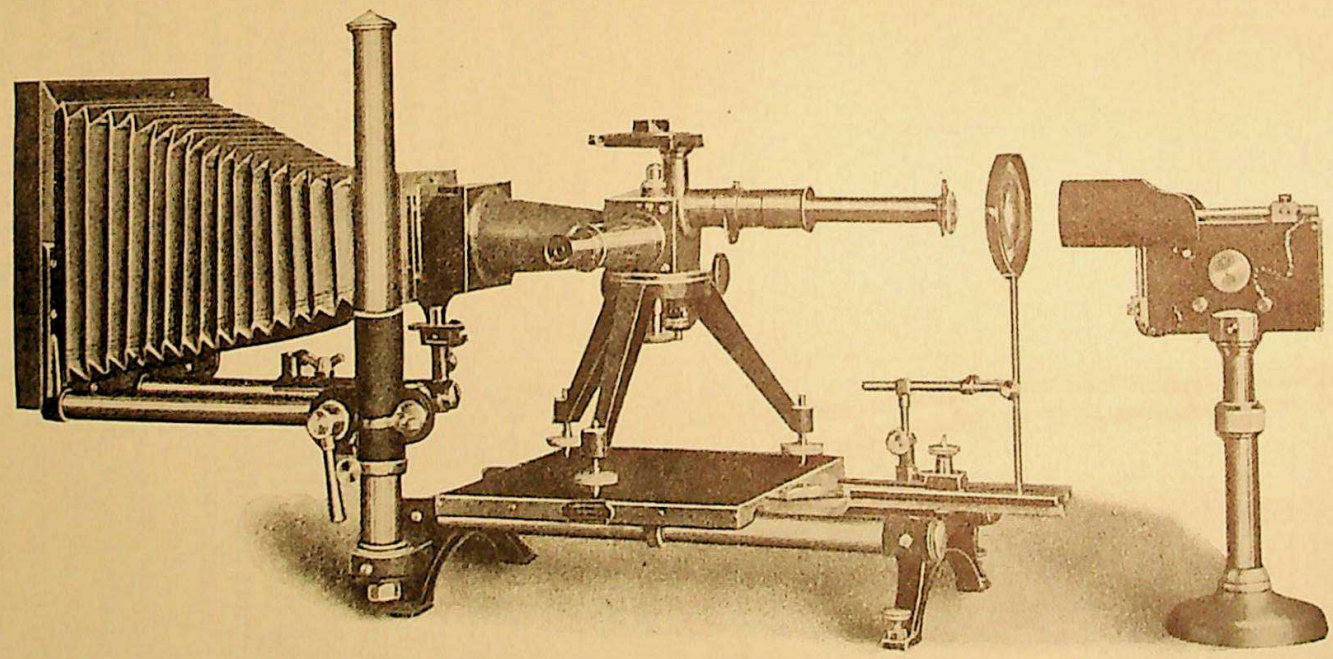


Fig. 19—Inverted metallurgical microscope. P. F. Dujardin & Co.

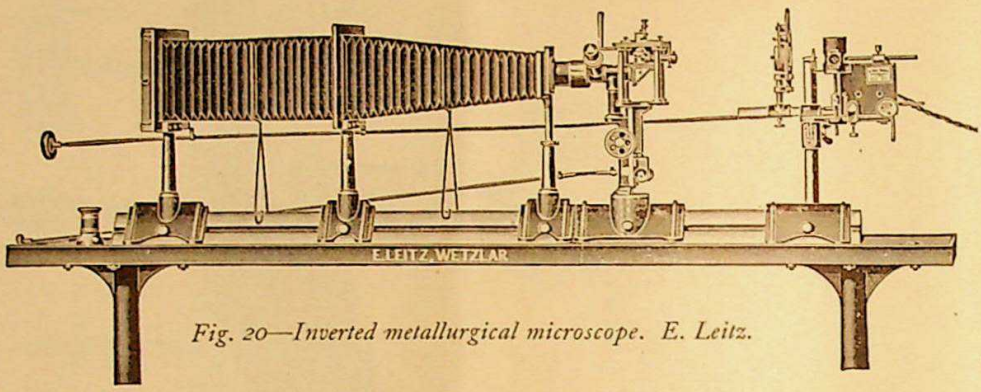


Fig. 20—Inverted metallurgical microscope. E. Leitz.

not exist. Furthermore, the fine adjustment has been mounted so that it is required to move a weight of only four ounces. When an illuminant of high intensity is used, considerable heat is bound to be received by the vertical illuminator. For this reason the objective is mounted independent of the vertical illuminator and whatever heat reaches the latter and causes it to expand will not change the distance between the specimen and objective and consequently will not cause the image to go out of focus. A heat guard is provided to prevent any light other than the centered beam from reaching any part of the microscope.

The body of the microscope consists of a casting in which is mounted a stellite mirror which reflects the image received from the objective towards the photographic plate. Over this stellite mirror is mounted the vertical illuminator. The body, including the eyepiece, stellite mirror and vertical illuminator are all in one rigid mounting. The pillar on which this body is mounted is short and sturdy. It extends vertically downward to the base and carries on it a rack slide.

The entire stage enclosing the microscope body is a single casting. Attached to the bottom of the casting is a rack and slide which moves on the pillar. Vertical motion is accomplished by means of the rack and pinion. The inner edges of the two stage posts nearest the camera are accurately milled, forming a double slide. A pair of pins, mounted in an upright which is securely fastened to the top of the body, maintain a constant pressure against these milled edges. This even tension on both sides of the stage posts, very near the surface of the specimen, assures perfect stability. (Figure 22.)

On the microscope pillar, opposite the stellite mirror position, is a strong, broad fine adjustment slide on which the objective support moves. (Figure 23). At the bottom of this slide is the fine adjusting mechanism which is required to raise and lower the objective and its mount only. The support for the objective is only slightly below the surface of the stage, and the fulcrum about which vibrations would take place is in the plane of the objective shoulder. This shoulder is level with the pair of pins which steady the stage.

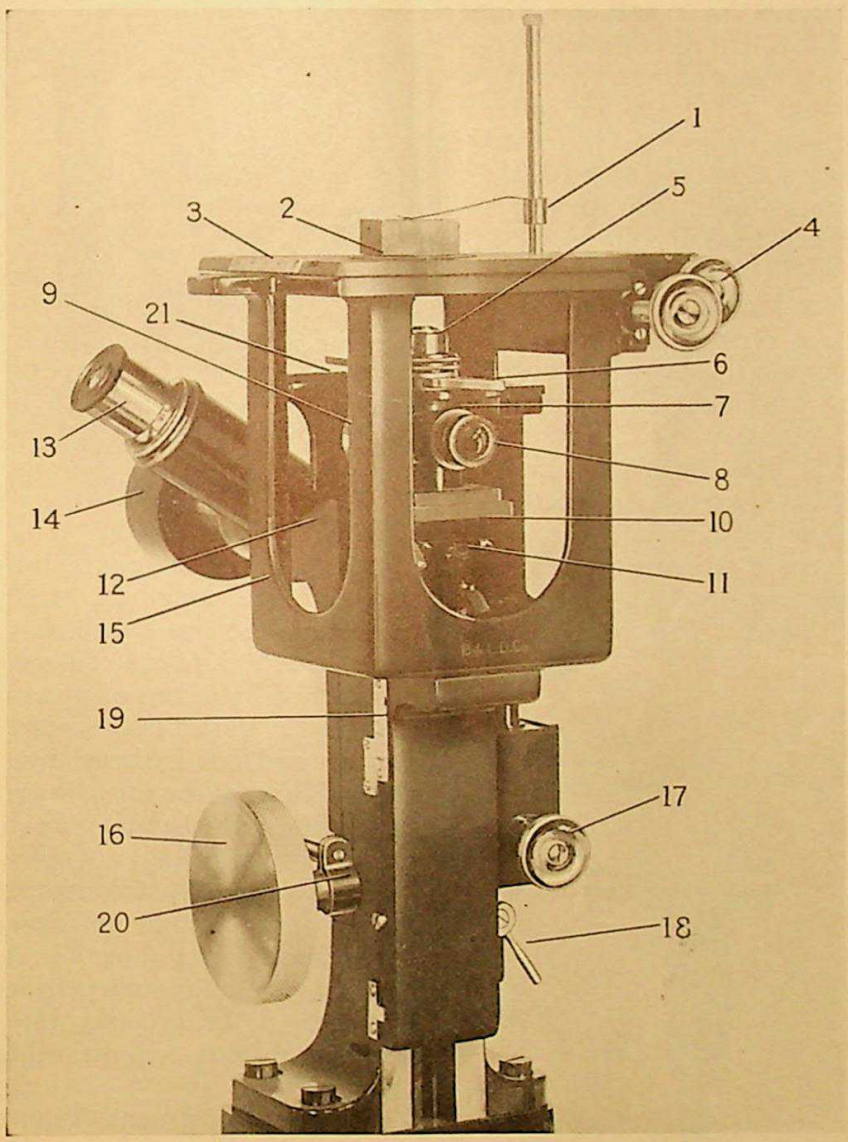


**Fig. 21—Bausch & Lomb Metallurgical Microscope.*

1. Specimen Holder
2. Stage Aperture Plate
3. Mechanical Stage Scale
4. Mechanical Stage Adjustment Heads.
5. Objective
6. Objective Handle
7. Iris Diaphragm Adjusting Ring
8. Filter Mount
9. Vertical Illuminator Mirror Mount
10. Stellite Mirror Housing
11. Heat Shield Socket
12. Microscope Body
13. Observation Eyepiece
14. Camera Connector
15. Stage Casting
16. Coarse Adjustment Head
17. Fine Adjustment Head
18. Reducing Gear Lever
19. Coarse Adjustment Scale
20. Coarse Adjustment Lock
21. Stabilizer

The screw that actuates the fine adjustment produces a vertical movement of 0.125 mm per revolution. A large diameter button may be brought into contact with a reducing speed shaft by moving a cam. This provides a more sensitive fine adjustment for use in focusing the image from the ground glass position. One revolution of the rod in focusing on the ground glass produces a vertical movement of the objective of only 0.03 mm. The fine adjusting head is graduated to read to 2.5 microns of vertical movement but may be estimated much closer.

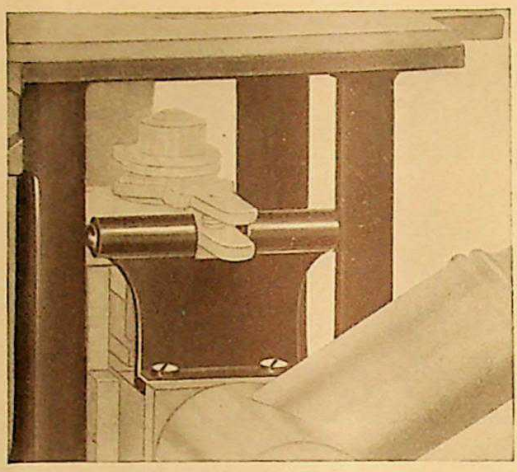


*Fig. 22—Lateral stage support stabilizer.

The coarse adjustment consists of a broad, heavy slide, on which the stage casting moves, actuated by a heavy rack and pinion controlled by knurled head. The position of the slide may be fixed definitely and securely after an approximate focus is obtained by means of a lock actuated by a convenient screw. This support and lock at the bottom, and the stabilizer at the top of stage support, as described above, effectually prevent any possibility of vibration.

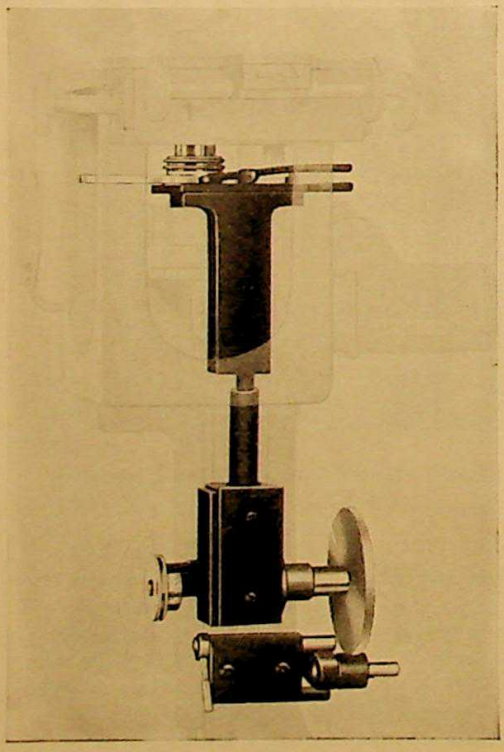


*Fig. 23—Fine adjusting mechanism (*Phantom view*).

The coarse adjustment operates by moving the stage and specimen with respect to the objective. A convenient scale and index permits the specimen to be brought into approximate focus for the objective being used.

The fine adjustment (Figure 23) consists of a broad dovetail slide, actuated by a knurled head and lever action, the same as on the finest biological microscopes. The slide is mounted on the pillar of the microscope so that it is movable with respect to the vertical illuminator. The slide is carried on a sturdy vertical rod, at the lower extremity of which is the fine adjustment mechanism and at the top a horizontal table on which the objective holder

is mounted. The latter is so designed that the objectives are easily interchangeable and are held against a shoulder and stop in such a way that they are positively centered with respect to the optical axis of the instrument.

This construction has a number of advantages over any previous designs of any manufacture. The most important, of course, is the fact that the fine adjustment carries the smallest possible weight so that regardless of the weight of the specimen on the stage there is no additional strain on the mechanism. In other constructions this mechanism carries so much weight that, where long exposures are necessary, it is often impossible to prevent the microscope slipping or settling out of focus during the exposure.

Another cause of change of focus in previous constructions is the effect of heat from the illuminant on the metal parts of the apparatus. The beam of light first enters the vertical illuminator through the filter and condenser, which absorb much of the heat and transmit some of it to their respective mountings which expand as a result. Where the objective is carried on the same fixture as the other optical parts, this expansion is bound to displace the objective with respect to the specimen so as to destroy the sharp definition at the plate. In this new construction, the objective being mounted independently of the vertical illuminator, no effect of the expansion of the parts is transmitted to the focusing adjustment.

A telescoping tube connector between the objective and the vertical illuminator excludes extraneous light and reflections from this part of the optical system.*

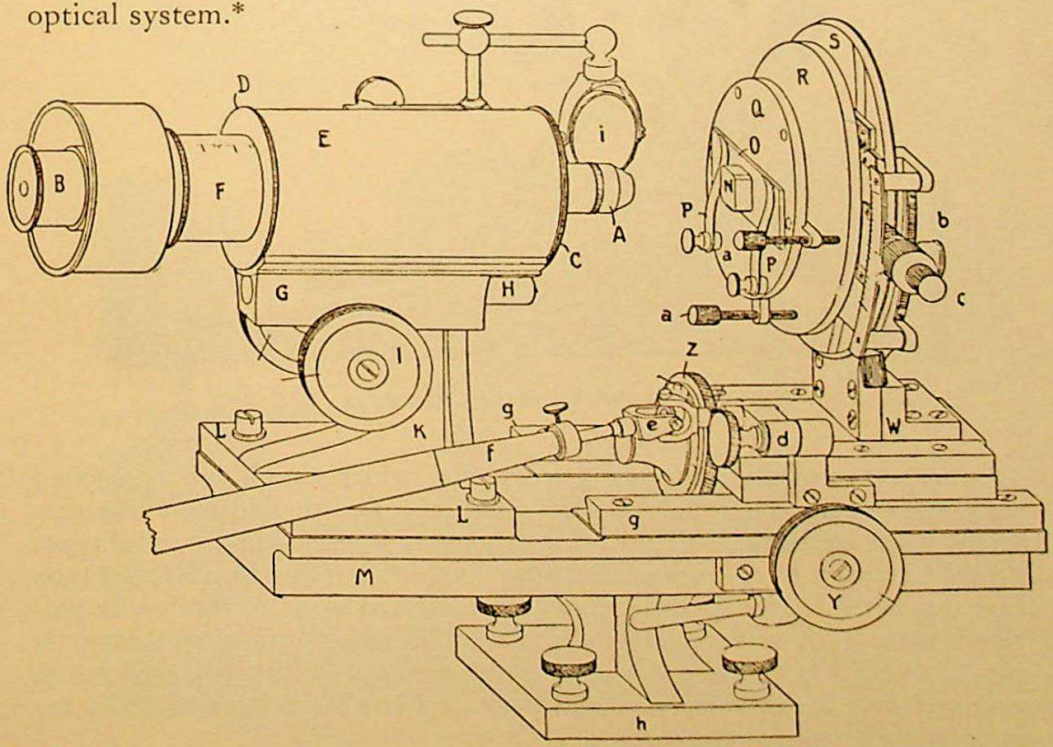


Fig. 24—Marten's metallurgical microscope. (Zeiss)

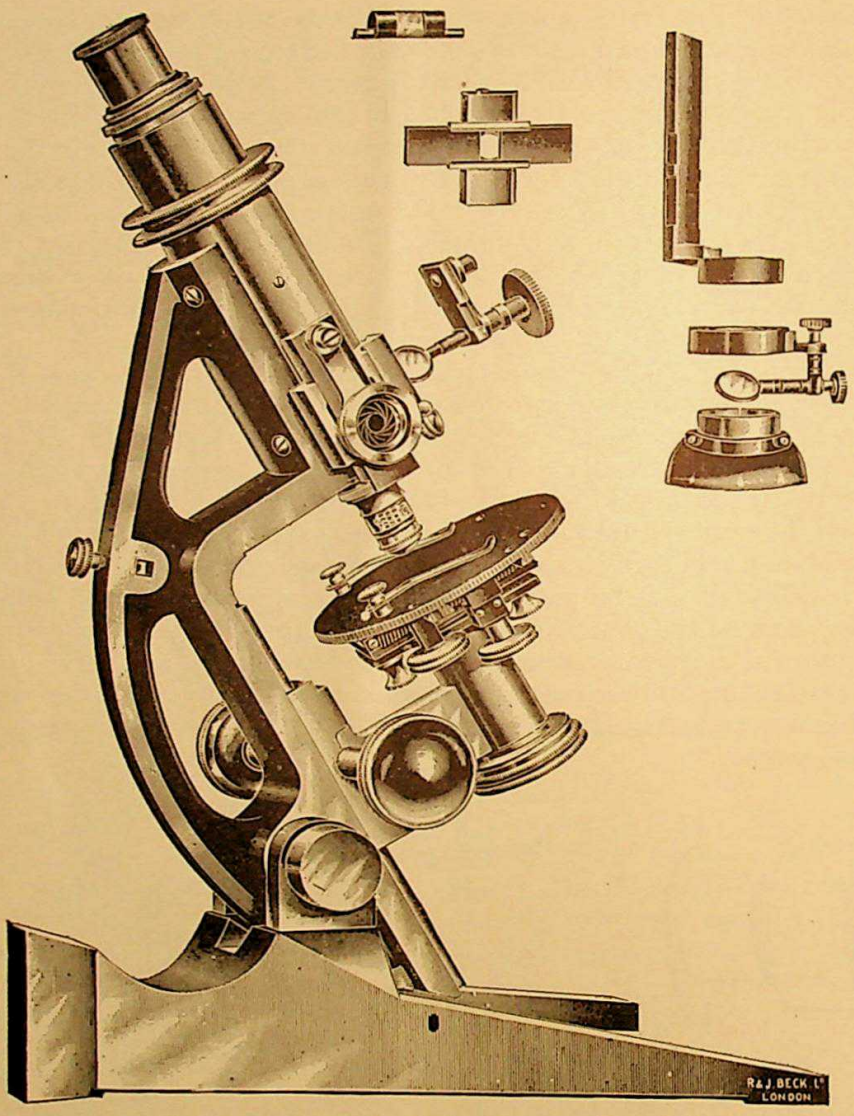


Fig. 25—Rosenhain metallurgical microscope. R. & J. Beck.

Other types of metallurgical microscopes which should be mentioned are those of Martens, made by Zeiss, (Fig. 24), and the Rosenhain microscope, made by Beck (Fig. 25). The Martens' stand is of horizontal type, provided with movable stage, and is in general form similar to the stands first described. The specimen must be mounted so as to retain the polished surface in a vertical position. The illuminating apparatus is placed at right angles to the axis of the microscope. The Rosenhain is an enlarged and heavy form of usual type and has its vertical illuminator built into the tube.

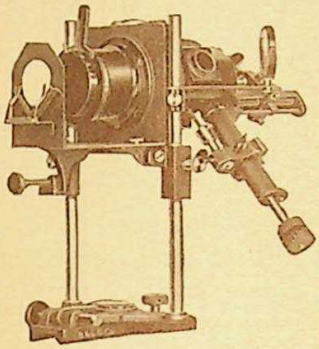


Fig. 26—Arc lamp. Hand feed type.

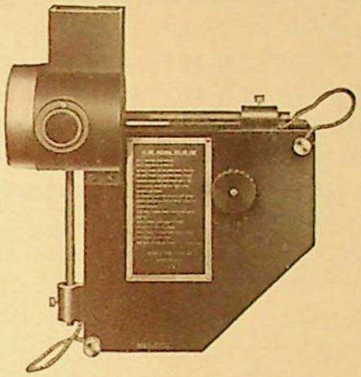


**Fig. 27—Arc lamp. Automatic feed type.*

The direct current arc of low amperage is no doubt the best illuminant to use if intensity is desired. The lamp may be of the hand-feed variety, but it is better to use a lamp having an automatic mechanism for feeding the carbons. Figure 26 shows a lamp of hand-feed type, and Figure 27 shows the automatic feed type, both lamps interchanging on the same standard. Suitable condensers must be used to collect a wide angle of the beam emitted from the lamp and condense it into the vertical illuminator. Centering screws are usually provided so that the illuminant can be well centered to the condensing lenses.

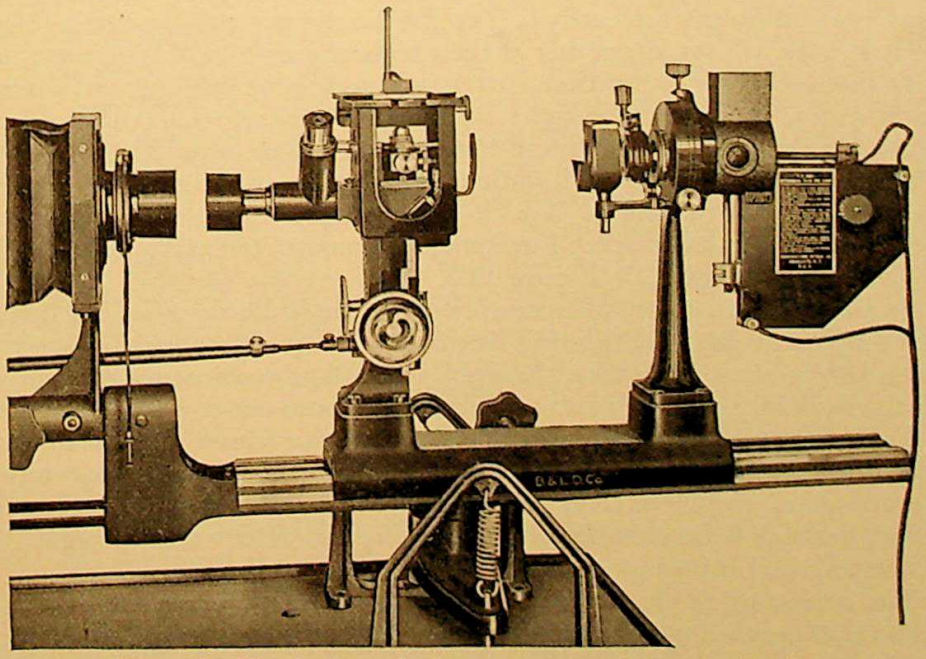


**Fig. 28—Illuminator and microscope mounted as one unit with permanently aligned optical system.*

The carbons used on direct current for 4 to 5 amperes are usually 8 millimeters diameter for the positive or horizontal carbon and 6 millimeters for the negative. It is necessary to see that the positive wire of the electric current is on the horizontal carbon. This can be determined by noting the brightness of the carbons through the smoked-glass window, the brighter one being the positive.

For alternating current the carbons should be 7 millimeters diameter for both horizontal and vertical, and it makes no difference how the wires are connected.

For visual observation and for photography where speed is not essential, a Mazda lamp with ribbon form of filament makes a very acceptable illuminant. It has the advantage of giving a constant and uniform illumination and requiring no care when once adjusted. This lamp, however, uses only 6 volts and is best used with an alternating current supply in connection with a transformer, as the amperage rating is 18.

In earlier models it was customary to have all of the different parts adjustable relative to each other on the optical bed and in both vertical and lateral directions. This was done so that the microscope, illuminating system and camera could be all aligned by the operator. For the operator who was trained in the manipulation of complicated optical apparatus this construction presented few difficulties of technique but did consume a great deal of time in the preliminary setting up of the apparatus every time work was to be done.

*Experience shows that there is no particular advantage in this construction. The experienced workman at the factory, by means of collimators and gauges can easily line up the illuminating and optical systems so that they will work together at their highest possible efficiency and then lock them securely in position. After this, no further adjustment is necessary except to bring the light source into center. The most critical technician can ask nothing more than a perfectly centered beam from the illuminant into the vertical illuminator regardless of the kind of illumination used on the specimen. This is the principle on which the Bausch & Lomb Large Metallographic Equipment is constructed and which is called "permanently aligned." (Figure 28.)

In the new instrument all accessories such as the liquid cell, filter holder, iris diaphragm and decentering device for oblique illumination are conveniently mounted between the light source and microscope and no adjustment of any of these parts can throw the beam out of its true center.

We believe, and experience has shown, that this construction is in every way the most satisfactory forward step taken in the photomicrography of metallurgical specimens since Le Chatelier introduced the inverted microscope, because it permits anyone to obtain satisfactory results regardless of their optical training or skill.

The mounting of the vertical illuminator on the microscope in a fixed position makes it a part of the permanently aligned system of which mention has been made above. Being in fixed position it is not thrown out of center with respect to the axis of the beam when the objective is focused

on the specimen by means of the fine adjustment, as is the case in instruments in which the vertical illuminator and objective are both carried on fine adjustment mechanism.

The vertical illuminator consists of a square metal box, mounted on the upper surface of the microscope base and having three openings. Facing the illuminant is a tube carrying the filter, iris diaphragm and condenser lens. At the top is the opening for the objective connector, while facing the operator is an opening carrying a shaft with knurled head at the outer end, which controls the clear glass reflector and prism for directing the illuminating beam up thru the objective. Either may be used, being interchangeable by a simple adjustment.

The filter supplied in the vertical illuminator mount, produces practically monochromatic light equivalent, to the E line of the mercury spectrum, which is the wave length for which the achromatic objectives are corrected. This wave length has been found to be the most satisfactory for all around metallographic work, particularly for iron and steel. In case other Wratten filters are to be used, they will be placed in the filter mount on the front of the liquid cell attached to the illuminating unit.

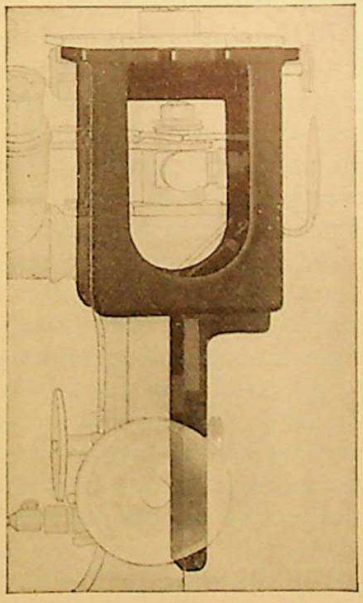


**Fig. 29—Microscope stage. Weight of stage and specimen centered over coarse adjustment slide.*

The full numerical aperture of the objective may be used, or the aperture may be reduced by means of the iris diaphragm in the tube directly back of the filter. The maximum resolution with any objective will be obtained when the full aperture of the objective is used. The flatness of field can be increased, with a sacrifice of resolution, by using a smaller opening. The ILS Microscope can be diaphragmed down to give a flat field—but in no photomicrographic outfit, metallographic or otherwise, can full resolving power and perfectly flat field be had at the same time.

The square object stage together with the support at each corner is cast in one solid piece, to increase the rigidity. This casting is mounted on a heavy L shaped part, the longer side of which is the slide which moves along the pillar of the microscope under control of a heavy rack and pinion, forming the coarse adjustment. The weight of the stage and specimen is located directly over the center of the coarse adjustment slide. (Figure 29.)

The slide of the coarse adjustment is dovetailed in cross section and is accurately milled and fitted. A clamping device on the coarse adjustment head locks the slide securely in place so that no sagging or vertical motion

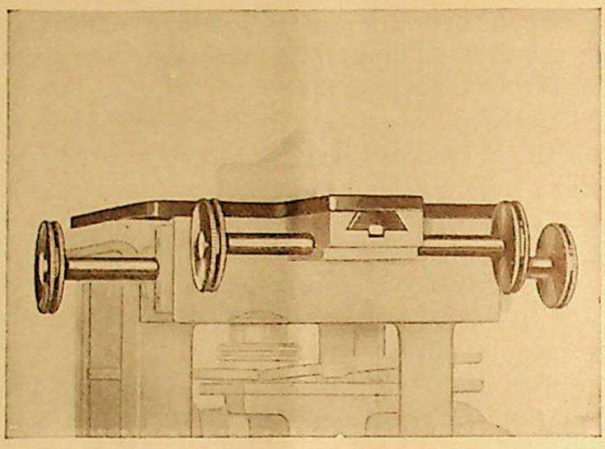


**Fig. 30—Mechanical stage. Adjustment heads on both sides of stage and all acting in same plane.*

can take place under the weight of the specimen during the longest exposures. As a precaution against the vibration of the stage relative to the other parts of the microscope, there is provided a stabilizer which prevents any lateral movement of the upper part of the stage, so that the latter is supported both top and bottom. The stabilizer consists of a Y shaped brace attached to the top of the microscope. In horizontal position at the top, it carries two ball ended shafts which bear against milled surfaces at each side of the stage supports. This brace is practically in the plane of the objective and effectually prevents any vibration of the specimen relative to the objective.

The mechanical stage, (Figure 30) which directly supports the specimen has two horizontal movements at right angles to each other, making it possible to thoroughly and systematically explore the surface of the specimen. These movements are controlled by a screw and rack and pinion actuated by two shafts rotating in the horizontal plane. The shafts bear knurled heads at each side of the microscope so that manipulation may be accomplished with either hand and in the most convenient position.

There is a 1¾" diameter opening in the center of the stage plate which is turned with a shoulder to hold a metal aperture plate. This plate has a long tapering opening which permits the use of any opening between 4mm and 11mm.

Projecting in the horizontal plane from the stellite mirror mount is the body tube of the microscope. This carries the eyepiece at its outer extremity, together with a light tight connector to exclude stray light when using the camera. Extending at right angles from the body tube is an auxiliary tube for visual observation. In visual observation a prism diverts the emergent beam from the stellite mirror into this observation tube, which is also equipped with an eyepiece. When focusing on the ground glass this prism is withdrawn from the optical axis. This arrange-

ment permits preliminary orientation and focusing of the specimen before the final focusing on the ground glass screen of the camera is undertaken. The entire arrangement is such that observation in the auxiliary tube, manipulation of the mechanical stage and focusing with the fine adjustment are all accomplished simultaneously in the most comfortable and convenient position.

The illuminant and its accessories are supported on a rigid stand that is a unit with the pillar which supports the inverted microscope. This stand supports, in order, the illuminant in its adjustable centering mount, the condensing lenses in a spiral focusing mount, the iris diaphragm and a water cell and auxiliary filter mount combined.

The illuminant regularly supplied with this outfit is the automatic feed arc lamp which must be used with a suitable rheostat for the ordinary 110 V current. The clock feed mechanism of the arc lamp operates the carbon holders by means of a constant chain drive, maintaining a steady and uniform arc of high intensity. The excursion of the carbon holders is sufficient to accommodate the entire length of 6″ carbons with one setting, giving nearly two hours of steady light.

Interchangeable in the same mounting is a 108 watt ribbon filament Mazda lamp in special housing. This provides a steady and uniform light, that is always in alignment. It is preferred by many because of its convenience and freedom from attention. As the intensity of the light from the Mazda is much less than that from the arc the length of exposure must necessarily be greater. However, if the equipment is to be used for extended periods of observation only, this lamp is recommended.

The large iris diaphragm is mounted in the optical axis of the instrument, just in front of the condensing lenses. It is held on a mount which is adjustable for rotation about the principal axis, for decentration in any direction to the extent of one half the radius of its total aperture and for total swing-out clear of the aperture of the condenser. The diaphragm will give any opening from less than two millimeters to over thirty millimeters and this construction permits the opening to be centered at any point in the total cross-section of the beam from the illuminant. This makes possible the illumination of the specimen by oblique illumination from any direction and a central stop may be readily inserted to provide for conical illumination.

The liquid cell is mounted on an arm between the diaphragm and the microscope. It consists of a metal box with glass windows in the light path. The glass plates are burnished in against rubber washers and are liquid and trouble proof. The cover of the cell is so designed as to also form a limiting aperture over one of the glass plates and a mount for a Wratten filter on the opposite side of the cell from the illuminant. The cell may be easily removed for cleaning or filling. It may be used either as a water cell for protecting the Wratten filters or as a liquid filter cell.

In the photomicrography of *transparent* specimens, two methods of illumination are in common usage. These are critical illumination, in which the image of the light source is focused directly on the specimen, and

Fig. 31—A camera especially designed for use with the side tube microscope.

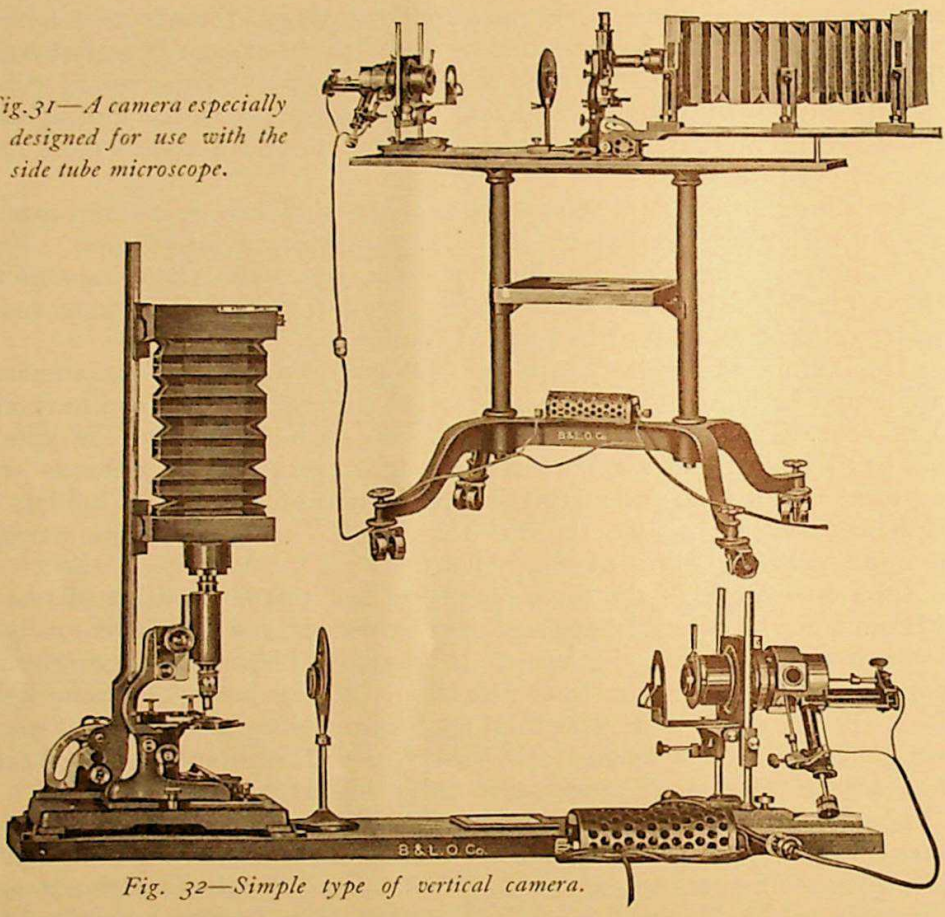


Fig. 32—Simple type of vertical camera.

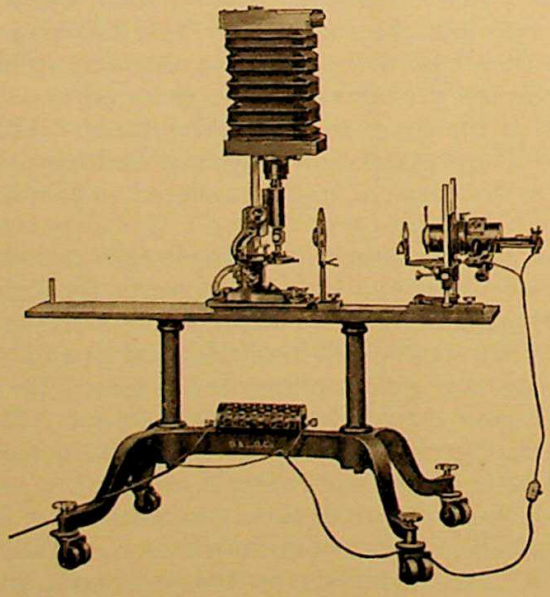


Fig. 33—A form of low stand with vertical camera.

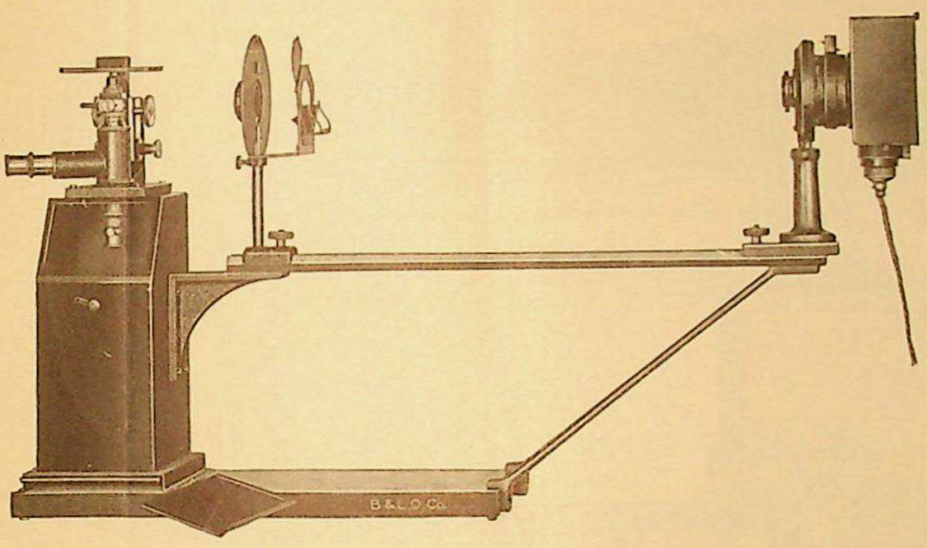


Fig. 34—Small metallographic outfit for student use.

Koehler illumination in which some evenly illuminated surface such as the condenser surface is imaged on the specimen. Where *opaque* specimens are concerned the critical system of illumination is preferable owing to the higher intensity of light on the surface of the specimen.

In this equipment the illumination is critical. The light source is first imaged by the two lens condenser. In the opening of the vertical illuminator, facing the lamp, is a lens having a focal length such that this source image appears at the microscope objective, to come from the plane of the diaphragm of the eyepiece. In other words, the source image is again imaged by the lens in the side of the vertical illuminator in a position conjugate to the specimen. Thus, when the objective receives the light, it forms an image of the light source practically on the surface of the specimen, presenting critical illumination as described above.

The image of the source on the specimen varies in size with the objective used. The size of the image, or illuminated area is slightly larger than the area of the field covered by the objective and 5 × eyepiece. No light goes to waste and when the objective is focused on the specimen the light is also focused on the specimen. Furthermore, the source image formed on the specimen is free from spherical and chromatic aberration. It is these reasons that make the illumination ideal in metallurgical microscopes. The highly corrected objective, with which the detail in the specimen is brought out, performs a double duty; it is first a condenser and then an objective.*

CAMERAS. — The cameras and supports available for this work probably are as great in variety as the microscopes. A few types will be referred to, all of which embody supports to carry an illumination system of the type described. Figure 32 shows a simple type of vertical camera which has been in use for a number of years. It differs from the ordinary,

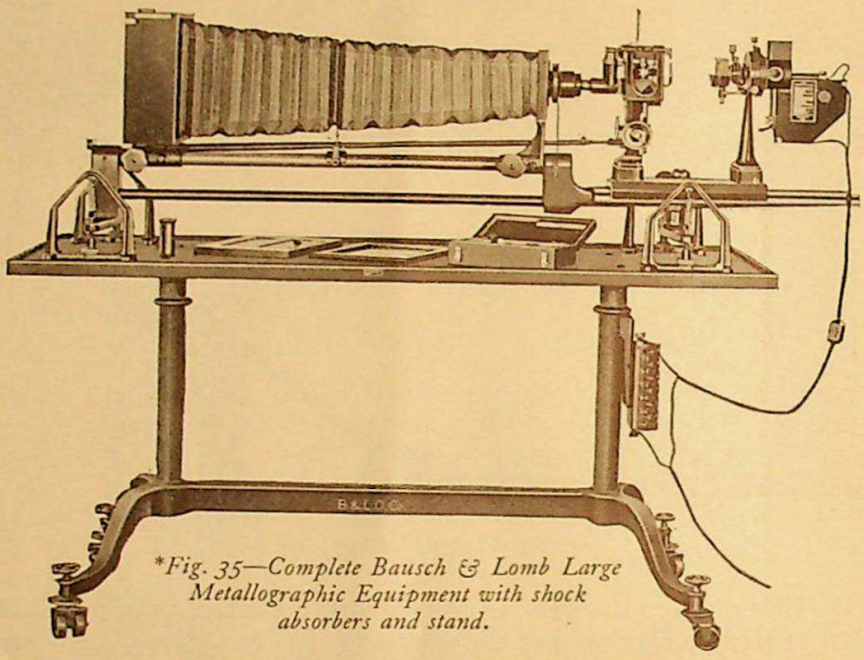


**Fig. 35—Complete Bausch & Lomb Large Metallographic Equipment with shock absorbers and stand.*

in that the camera and all accessories are mounted on a single base board to which they can be clamped after adjustment. It is annoying in this work to have a number of loose parts which are readily disturbed. Figure 33 shows a low form of stand with vertical camera. When resting on the floor the ground glass is at a convenient height for observation. The camera may be swung to one side when making adjustments of the specimen and illumination.

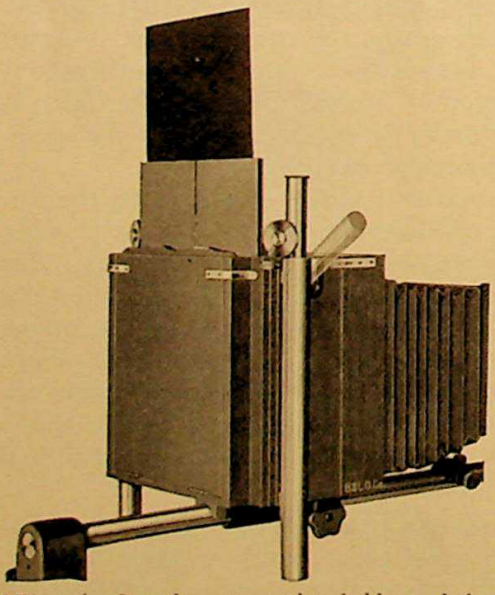


**Fig. 36—Supplementary plate holder and viewing device with viewing tube in position for observation.*

Figure 31 shows a type especially designed, after suggestions of Professor Sauveur, for use with the side-tube microscope. As stated, when referring to the microscope, the side tube is withdrawn for visual observation and again pushed into the path of light when making photographs. The light-tight connector between camera and microscope is so made that neither camera nor microscope need be moved in making the adjustment from visual to photographic use. All the camera supports described are made with either 4 by 5 or 5 by 7 inch cameras.

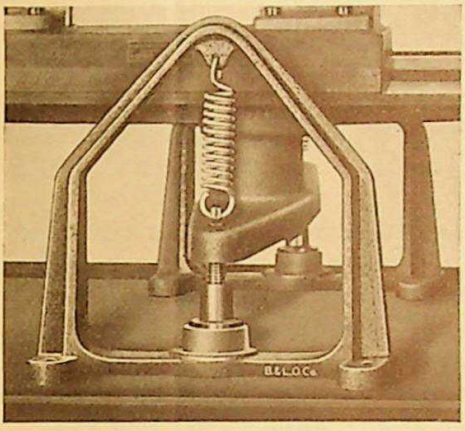


*Fig. 37—Shock absorbers, showing frame, spring and adjustable rubber damper.

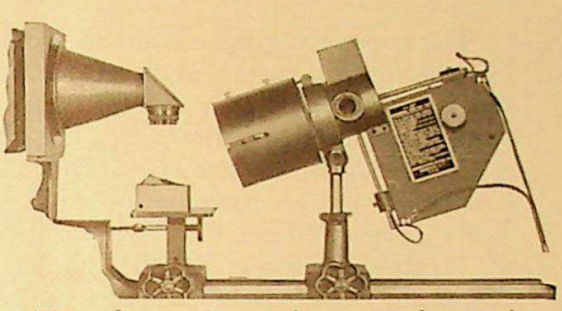


*Fig. 38—Attachments for macro-photography, showing arc lamp tilted for oblique illumination.

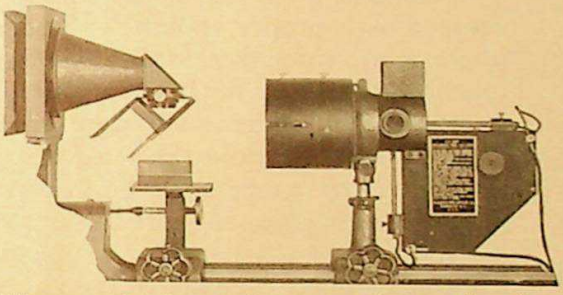


*Fig. 39—Attachments for macro-photography, showing arc lamp in position for vertical illumination.

The camera shown in figure 34 is a small outfit for student use and for industrial plants where only a small amount of work at low and medium powers is required. The microscope is of the inverted type and is mounted over the camera. The specimen is examined by means of a side tube, which, with its prism, may be withdrawn from the optical axis, permitting the image to fall upon the plate in the camera. While the image may be focused upon an opaque screen in the camera, it is possible so to adjust the camera eyepiece that the image is sharp upon the plate when focused for visual observation. The illuminant is the 6-volt, 108-watt Mazda lamp. The mountings for lamp and the condensers are of much simpler form than in the previous outfits, but will give satisfactory results in magnifications from 50 to 400.

*Figure 35 shows the complete Bausch & Lomb Large Metallographic Equipment, the microscope and illuminating unit of which has already been described.

The camera parts consist of a tapering bellows of 40″ extension, with front and rear supports and center frame to prevent sagging. The camera back is reversible and is provided with a hinged door, single book form of plate holder for 8 x 10 plates with reducing kits for smaller sizes down to 3¼ x 4¼, one ground glass screen with clear center for use with focusing glass and a clear glass screen with graduated cross lines. The front support is fitted with an exposure shutter and light tight connector for connecting with microscope. An extension rod for moving the fine adjustment while observing the image on the ground glass, and a focusing glass are included in the camera equipment.

The supporting base is made of two parts—a heavy, steel double bar for the camera parts and a section of accurately milled optical bed for the microscope. They are carefully joined together and provided with low supporting feet at either end. The supports for the camera, slide very easily along the bar because of the long bearing surface and are prevented from tipping by a tongue running in a groove on the side of the bar. The bar is graduated in millimeters for the easy determining of bellows draw.

A new camera back, Figure 36, has been developed to make the focusing of the image easier and more positive, and to eliminate vibration in the manipulation of the dark slide.

It consists of a frame interposed between the rear bellows frame and the camera back proper, in which there is mounted a magnifier with a right angle prism which faces toward the eyepiece of the microscope. To focus, one has but to look in the magnifier and adjust the fine adjustment of the microscope until the image is in focus on the cross hairs.

As these are located the same distance from the prism as the plane of the plate, the image must be in focus in that plane. The magnifier is mounted on a pivot support so it may be moved across the entire field.

In this new back there is a supplementary dark slide which is raised by counter balanced weights running in cylinders on either side. With this device it is possible to withdraw the regular dark slide from the plate holder, permit the equipment to come to rest, check up on the focus with the magnifier, swing it aside, close the shutter, release the catch on the supplementary dark slide, permitting it to automatically rise without any vibration and then make the exposure. This arrangement will be readily appreciated by all photomicrographers. It can be attached to any of the type G cameras now in use. Trial exposures may be made by withdrawing dark slide, giving the plate an exposure of 15 seconds; replacing the slide one inch at a time, giving each succeeding inch 15 seconds, so that the final exposure on a 5-inch plate would be 75 seconds, 60 seconds, 45 seconds, 30 seconds and 15 seconds for the various parts. After some experience it is easy to judge the correct exposure for a given class of objects.

It is a recognized fact that the vibrations caused by machinery, street traffic, etc., must be absorbed before successful photomicrographs can be taken. The Bausch & Lomb Shock Absorbers (Figure 37) consist of four unit supports, each unit of which is made up of a sturdy frame, one coiled spring, a sponge rubber damper and a threaded secondary support for adjusting the pressure on the rubber damper or absorber.

Figure 38 shows an arrangement for attaching low-power photographic lenses, of the 32-, 48-, and 72-millimeter foci, to camera, and special device for holding and focusing the specimen. The focusing is done by extension rod from rear of camera while observing the ground glass. It is intended for the photography of fractures, etc. This also shows the illuminant as used for oblique illumination. Plane glass holders are supplied for vertical illumination with these low-power lenses, as shown in Figure 39.*

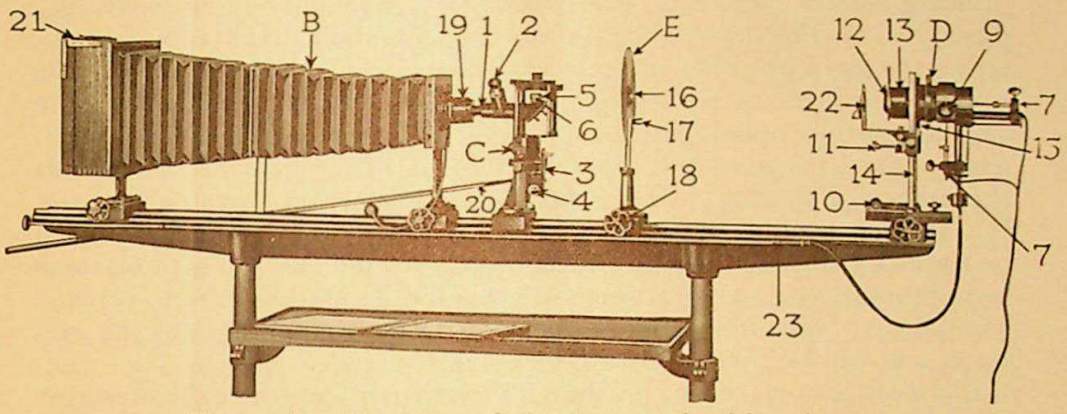


Fig. 40—Metallographic outfit with parts numbered for reference.

ADJUSTMENTS

Many of the difficulties in the use of metallographic equipment are due to improper adjustment of the illuminating and optical parts. The later models of the Bausch & Lomb Large Metallographic Equipment are permanently aligned at the factory by means of collimators and gauges so that the greatest possible efficiency is obtained. As the various parts are fixed in position there is no possibility of this arrangement being disturbed and no time is lost in making the preliminary adjustments each time the apparatus is to be used.

This model is, however, comparatively recent and there are many of the older models as well as those of other makes in use, in which it is necessary to align the optical parts. For this reason a brief description of the process is here given, the principle of the operation being sufficiently

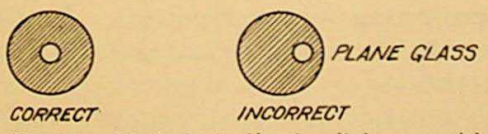


Fig. 41—Method of adjusting light spot with plane glass.

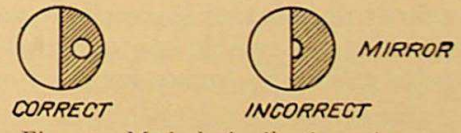


Fig. 42—Method of adjusting mirror illuminator.

similar in all cases to make these directions applicable. Number references are to parts indicated in Figure 40.

One of the main points is the centering and focusing of the illuminating pencil or cone of light. If this is incorrect, good results cannot be obtained. First see that the plane glass of the vertical illuminator is set an angle of 45°. Place a highly polished, unetched specimen on stage face down, focus objective, and while observing in the eyepiece bring the small spot of light to the center of the field. The spot should appear as the one in Figure 41 marked correct. If it is off center, the vertical illuminator should be adjusted either by knob of plane glass No. 6, or by rotating the illuminator upon the verticle axis until the spot is centrally located.

Going back to Figure 40, focus the objective roughly and remove eyepiece, No. 2. Place over the eyepiece tube a pinhole diaphragm, for centering the eye with tube. Place supplementary lens, E, in position about 6 inches to right of microscope, and while observing through pinhole cap, adjust this condenser until the bright spot is in center, as just shown. Then replace eyepiece and close iris, No. 16, of supplementary lens. If the iris is not sharply defined, slide the supplementary lens on its base, No. 18, to or from the microscope until the blades of iris diaphragm can be distinctly seen in the field, when objective is in focus. In making these last observations, a smoked-glass cap should be used over the eyepiece. The image of this iris should be concentric with diaphragm of the eyepiece, and will be if set-up has been correctly made.

If the arc is now focused on the supplementary lens, the light condition should be as shown in Figure 13. The arc is nearly focused on supplementary lens No. 2, by lens No. 1. Lens and iris No. 1 are focused at back of objective by lens No. 2. Arc, lens, and iris No. 2 are focused on specimen by the objective. This gives critical illumination. When these results are obtained, good images are secured. After a little practice it is not difficult to set up the apparatus in the manner described. Some users introduce a ground glass in front of the arc. This diffuses the light, and while giving even illumination, it does not give critical illumination as previously described, but is preferred by some for lower powers and is even recommended by some workers.

In adjusting the mirror illuminator, or if a prism illuminator is used, the same conditions prevail. The spot of light is to be centered in the field as before, and the supplementary lens then placed in position and the location of the light pencil adjusted as shown in Figure 42. In this case it will be noticed that in the correct position the circle of light is located in the middle of the hemisphere and not centrally with the optical axis. The mirror illuminator is excellent for projecting with low powers. A little practice will enable one quickly to make these adjustments, and the results will amply repay for the time spent.

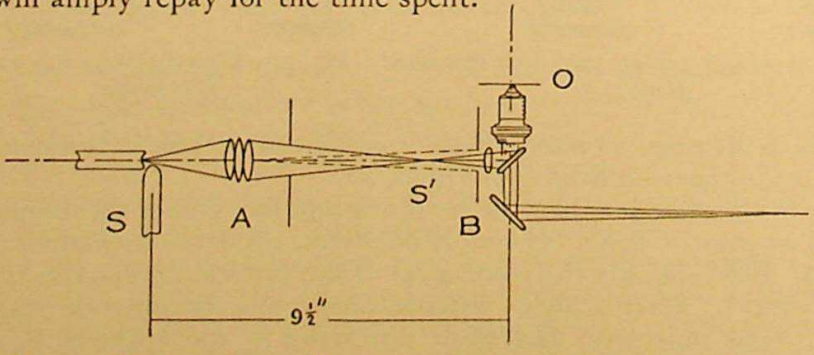


Fig. 43—Diagram showing illuminating system with short focus condenser.

*The most recent models (1927-8) are arranged, as shown in Figure 43, with the source of illumination 9½ inches from the axis of the microscope. Such an arrangement permits critical illumination and makes a more

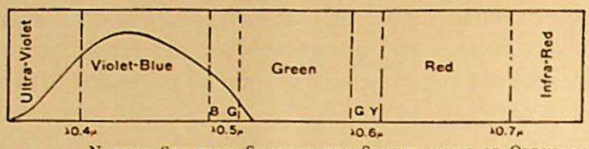
compact instrument with fewer adjustments. This reduction of the distance from the light source to the vertical axis is accomplished by a short-focus condenser and a supplementary lens to magnify and form a virtual image of the light source.

The light source S (Fig. 43), is imaged at S′ under a magnification of about 1.5 by the short-focus condenser A. B is an auxiliary condenser placed very close to the axis of the microscope and of such focal length as to form a real image of the condenser A in the back focal plane of the microscope objective. The auxiliary condenser B must also form a virtual image of the light source S′ in the conjugate focal plane of the objective. That is, the lens B places the light-source image to the left, at a distance from the objective equal to the distance to the right from the image plane to the objective, or at a position such that the objective will image the light-source S on the specimen O. Thus, critical illumination results, and we have a short system of illumination performing the same as that represented in Figures 13 and 40.*

The elimination of vibration is one of the difficult problems that most metallurgists have to overcome. No matter how rigid the apparatus, short sharp blows will produce vibrations which make it impossible to make good photomicrographs. There are a number of different devices in use ranging from simple to very elaborate appliances. Each user seems satisfied with his particular device. Probably the simplest and easiest to install consists of two planks, of a size suitable to hold the entire apparatus, and between them two inflated 3½ inch inner tubes or two circles of tennis balls.

Another device much in use consists of a platform suspended from the ceiling, some consisting of simple chains or ropes, others of springs arranged with oil dampers below platform to check the spring movement. Another device, designed by Mr. Pafenbach of the Simonds Stell Co., Lockport, New York, consists of a submerged platform level with the floor, but suspended upon springs held by angle pieces projecting downward from cross beams, also level with the floor. It seems that each one might best provide such means as are necessary in his particular location, but vibration, if it exists, should be eliminated. Vibration can be detected easily by observing the reflections from a small dish of mercury set upon the apparatus.

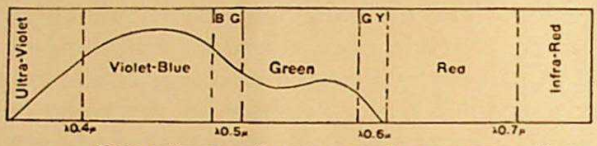
A focusing glass is a desirable addition, and almost necessary if one expects to obtain a sharp image upon the photographic plate, especially in high magnifications. As to the proper color of filter to use in metallography, there seems to be some differences of opinion, no doubt due to differences in plates, illuminants, objectives, and specimens used by different workers. Different colors have been experimented with, and it has been found that on iron and steel specimens a combination of green and yellow dominant wave length of 5500 Angstroms give the best results. The Angstrom unit equals one ten-millionth of a millimeter. Often the appearance of the image upon the ground glass is made the basis of the proper filter to secure contrast desired, but suitable plates must be used to



NORMAL SPECTRUM SHOWING THE SENSITIVENESS OF ORDINARY PHOTOGRAPHIC PLATES.

(After Mees, and magnified as in fig. 139).

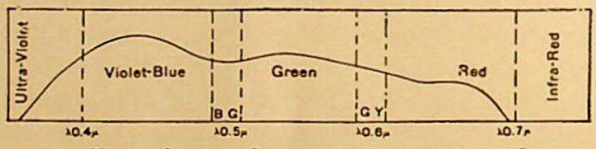
Fig. 44—Sensitive region of the ordinary photographic plate.



NORMAL SPECTRUM SHOWING THE SENSITIVENESS OF ORTHOCHROMATIC OR ISOCHROMATIC PLATES.

(After Mees; magnification as in fig. 139).

Fig. 45—Sensitive region of orthochromatic or isochromatic plates.



NORMAL SPECTRUM SHOWING THE SENSITIVENESS OF PANCHROMATIC PLATES.

(After Mees; magnification as in fig. 139).

Fig. 46—Sensitive region of panchromatic plate for a wide range of the spectrum.

record such an image. Much difficulty is found in obtaining solid glass filters that will give the color desired, so it becomes necessary to use the glass-mounted, gelatine-stained variety. In the matter of plates one must select a plate suitable to the work and filter used.

Figure 44 shows the sensitive region of the ordinary plate, and if filters are used which transmit only green and yellow with very little blue, the exposure will be very long and the results not satisfactory. Figure 45 shows the sensitive region of the orthochromatic or isochromatic plates, and if filters are used, such as the B & G Wratten, transmitting wave lengths around 5500, this type of plate gives good results. The slower orthochromatic plates have a finer grain and are therefore best for photomicrographic work. Such plates as the Stanley Commercial or the Cramer Slow Iso will give good results. If heat-tinted specimens are used and there is much variation in colors, all of which one may wish to record, then the panchromatic plate should be used. Figure 46 shows that these plates are sensitive to a wide range of the spectrum.

The many factors involved, such as objectives, aperture, magnification, illuminant, filter, etc., make the keeping of records almost imperative. A method of standardizing a photomicrographic outfit has been described by Prof. Alexander Petrunkevitch of Yale University in the Anatomical Record, Vol. 19, No. 5, October 1920. While his article refers particularly to transparent photography, the same rules can be applied, namely, to

determine the best location for each and every part of the apparatus, diaphragm apertures, for different objectives, ray filters, plates, etc., and after establishing such record, one may make a picture of a given kind of object in the minimum amount of time and be practically sure of the result without recourse to cut and try methods every time a picture is to be made.

The surface of the polished specimen must be flat. Any rocking on the grinding or polishing wheel will produce a cylindrical surface and the field in the microscope will have a band in focus while both sides may be out of focus. Also, the etching must be done properly to produce the contrast necessary to show the structure desired. Light etching has been found to give the best results with high powers. It is well again to emphasize the necessity of keeping all parts of the apparatus clean, not only all lenses, but all bearing surfaces. The apparatus should be protected with a rubber cloth covering when not in use. The instrument should be placed, if possible, where it is not exposed to the fumes of the chemical laboratory.

Table of Magnifications For ILS Inverted Microscope

OBJECTIVES		Eyepiece Power	Distance from eyepiece to screen in CM			
E.F. in MM	Magnification		25	50	75	100
Achromatic System		5.0	25	52	78	104
		6.4	33	66	99	132
		7.5	39	78	117	156
32	5.2	10.0	52	104	156	208
		12.5	65	130	195	260
		15.0	78	156	234	312
		5.0	62	124	186	248
		6.4	80	160	240	320
		7.5	94	188	282	376
16	12.5	10.0	125	250	375	500
		12.5	156	312	468	624
		15.0	188	376	564	752
		5.0	130	260	390	520
		6.4	166	332	498	664
		7.5	195	390	585	780
8	26	10.0	260	520	780	1040
		12.5	325	650	975	1300
		15.0	390	780	1170	1560
		5.0	262	524	786	1048
		6.4	335	670	1005	1340
		7.5	392	784	1176	1568
4	52.3	10.0	523	1046	1569	2092
		12.5	654	1308	1962	2616
		15.0	785	1570	2355	3140
		5.0	583	1166	1749	2332
		6.4	746	1492	2238	2984
		7.5	874	1748	2622	3496
1.9	116.5	10.0	1165	2330	3495	4660
		12.5	1456	2912	4368	5824
		15.0	1748	3496	5244	6992
Fluorite System		5.0	258	516	774	1032
		6.4	330	660	990	1320
		7.5	387	770	1161	1548
4	51.6	10.0	516	1032	1548	2064
		12.5	645	1290	1935	2580
		15.0	774	1548	2322	3096
		5.0	600	1200	1800	2400
		6.4	768	1536	2304	3072
		7.5	900	1800	2700	3600
1.8	120	10.0	1200	2400	3600	4800
		12.5	1500	3000	4500	6000
		15.0	1800	3600	5400	7200
Apochromatic System		5.0	140	280	420	560
		6.4	179	358	537	716
		7.5	210	420	630	840
8	28	10.0	280	560	840	1120
		12.5	350	700	1050	1400
		15.0	420	840	1260	1680
		5.0	291	582	873	1164
		6.4	372	744	1116	1488
		7.5	436	872	1308	1744
4	58.2	10.0	582	1164	1746	2328
		12.5	728	1456	2184	2912
		15.0	873	1746	2619	3492
		5.0	370	740	1110	1480
		6.4	477	948	1422	1896
		7.5	555	1110	1665	2220
3	74	10.0	740	1480	2220	2960
		12.5	925	1850	2775	3700
		15.0	1110	2222	3330	4440
		5.0	555	1110	1665	2220
		6.4	710	1420	2130	2840
		7.5	833	1666	2499	3332
2	111	10.0	1110	2220	3330	4440
		12.5	1388	2776	4164	5552
		15.0	1665	3330	4995	6660

NOTE: Above objectives are short mounted and corrected for 215 mm tube length.
The first column of magnifications represent visual magnifications as well as that on the ground glass at 25 cm.